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MECHANICS OF WATER EROSION

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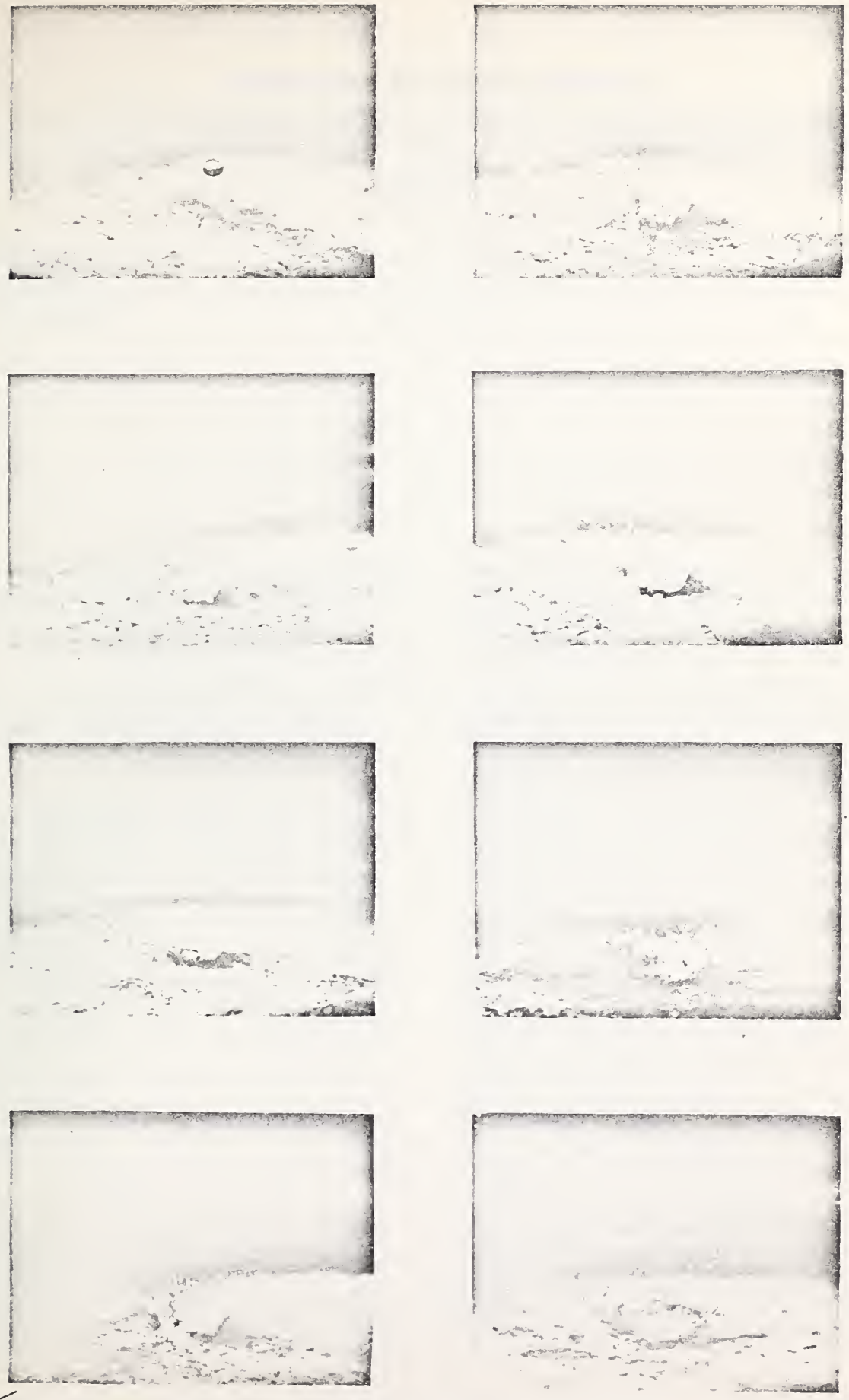

Figure 1.--This photograph shows the splash resulting from a falling drop of water striking bare soil surface. The drop of water fell from a height of about 7.5 feet. The set of photographs shows a succession of stages in the splash action. The final product is the crater shown in the photograph in the lower right-hand column.

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Erosion by water has been going on since the beginning of time, but its progress has been accelerated by the activities of man. This has been due primarily to man's stripping the mantle of native vegetation from the soil and his subsequent misuse and mismanagement of the land. Sediment-filled reservoirs and stream channels, gullies, eroded abandoned land, and the remains of once prosperous civilizations bear mute evidence of the destructiveness of erosion.

Water causes erosion by detaching soil particles from the surface soil mass and transporting it, mostly downhill. It may do this on any area where there is natural precipitation or where water is applied artificially to land surfaces. Water's erosive action is greatest and most destructive where the protective cover of vegetation has been removed, exposing bare land surfaces to the direct action of rainstorms.

The movement of soil by water is a complex process. It is influenced by the amount, intensity and duration of rainfall, amount and velocity of surface flow, nature of the soil, ground cover, slope of the land surface, and many other factors. In each case, the erosive power of water is determined by the interaction or balance of several factors, some favoring soil movement and others opposing it. Soil material must first be dislodged from its position on the surface of the land before it can be transported. It may then be splashed, rolled, slid, or carried in suspension along the surface. These processes are largely the result of raindrop splash, turbulence of moving water caused by raindrop splash, and flowing water.

Differences in soil erodibility suggest that both inherent soil properties and those brought about by land use, especially by cultivation and other man-caused disturbances, play a major part in the water-erosion process.

Erosion, in its physical aspects, is simply the accomplishment of a certain amount of work in tearing apart and transporting soil material. The erosion process begins when raindrops strike the surface of the soil and break down the clods and aggregates (fig. 1) or when snow melts (fig. 2). It consists of three principal, sequential steps. In the first step, the soil particles are torn loose from their moorings in the soil mass. In the second step, detached soil material is transported. And in the third step, soil material is deposited. The products of the first two processes cannot be expressed in a single quantitative result, because they cannot be expressed in like units. Detachment is expressed in terms of weight or volume per unit area, such as tons per acre. Transportation, on the other hand, is properly expressed in terms of weight or volume moved through distance, such as ton-miles per acre.

The two principal erosive agents that become active on land during rainstorms are falling raindrops and flowing water. The energy of falling raindrops is applied from above, and their principal function is to detach soil particles from the soil mass (fig. 3). The energy of flowing water is usually applied parallel with the surface and, outside of rills and gullies, its principal function is to transport soil material (fig. 4). Both raindrops and flowing water are complete erosive agents in themselves, but in one phase of the erosion process they work together. That is when there is a thin surface flow, in prechannel stages, which lacks rotational energy to keep soil in suspension. Then

6-1674

Figure 2.--Erosion damages caused by snowmelt occurs in two distinct forms, that is, rills and gullies, as shown across the center of the photograph, and landslides, as shown in the left background. Water from melting snow usually concentrates into channelized flow to form rills and gullies. In some cases, where the surface soil is underlain with an impervious layer, water seeping into the ground collects on top of this impervious layer to act as a lubricant and the soil above it sloughs off.

the falling raindrops, by keeping the water turbid, impart the ability to transport soil particles to such surface flows (fig. 5).

Falling raindrops and surface flow produce widely different effects on the soil. The force of falling raindrops is applied uniformly over the whole surface on which the rain falls. Erosion caused by raindrops is more of a smoothing, or leveling, agent (fig. 6). This is demonstrated on a small scale by the way the beating raindrops flatten small sandpiles by bringing soil material from the crest and depositing it lower on the slope. Flowing water tends to collect in channels--first, in small rills and then, as these small channels converge, in streams. The result of erosion caused by the flowing streams is to roughen the surface by cutting channels, or gullies.

Splash-Erosion Process

The erosive capacity of a falling mass of water depends on the energy per unit area of the individual drop. The kinetic energy of the falling drop determines the force of the blow that must be absorbed at each point of impact, while the horizontal area of the drop determines the amount of soil that must sustain that blow. It is the application of this energy in the form of raindrop impact that accounts for the greatest part of the dispersion of soil particles (5, 11)[1]. At the same time, it affects the infiltration capacity of the soil and thus determines the amount of rainwater lost as runoff. We know now that, on some terrain, the washoff soil losses alone actually account for only a small part of the erosional damage from a heavy rain. The rest of the damage is attributable to soil splash (5, 11) (fig. 3). The secret of preventing most erosion, therefore, is to remove this energy from the raindrop before it is brought to bear on the surface of the soil.

The kinetic energy of raindrops amounts to 10^4 ergs for drops of 2 mm. radius (11). The kinetic energy contained in a drop 2.5 mm. radius is sufficient to raise by 1 cm. a body weighing 46 grams. As the intensity of rainfall increases, the kinetic energy increases at the rate of 1.2 powers of the intensity. All of the kinetic energy of the raindrops, except a small part which is transformed to sound and heat energy, is expended instantly against the soil surface (11). The movement of soil caused by the impact of falling raindrops is downward, to

[1] Figures in parentheses refer to Literature Cited.

1134

Figure 3.--About 2 inches of soil were removed from this plowed field, mainly as a result of raindrop splash. The stone-capped pedestals show that the force causing the erosion was applied from above, as by falling raindrops, and not from the side, as by flowing surface water. The dead plant roots in the foreground protected the soil immediately beneath them while that between and to the side of them was splashed away.

14-1266

Figure 4.--Falling raindrops beating on the unprotected ground surface of this cornfield splashed particles of soil into the air. These particles fell into the thin film of water that was on the surface and were floated downhill, to be deposited when the gradient of the slope was decreased and the velocity of the flowing water was consequently reduced.

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Figure 5.--The effects of raindrop splash in the erosion process frequently are most pronounced on the short, steep slopes near the crest of hills. Under such conditions falling raindrops are most effective in moving soil downhill without much assistance from flowing surface water.

the sides, and upward. The downward movement consumes the greater part of the kinetic energy of raindrops at the beginning of a rain. The movement to the sides and upward is related to the spreading and splashing action of raindrops.

The compacting action by the falling raindrops causes soil to suddenly lose its capacity to infiltrate water. It is thus responsible for the high runoff during heavy rains. This is illustrated by the fact that rain falling on sand decreases its infiltration rate without producing turbid water. Where the energy of the falling raindrops was reduced by the use of wire gauze suspended a short distance above the surface, however, the rate of water intake remained high and showed no sign of slowing down after a considerable lapse of time (11). It did not slow down even when the degree of slope was increased.

When the surface soil was pounded by raindrops, the infiltration rate decreased rapidly as the proportion of large drops and their velocity increased. In the same rainfall, the decrease in the infiltration rate was greatest on the flatland. The decrease was progressively less as the degree of slope increased. The hammer-like action of the raindrops brings more direct and stronger pressure to bear on the flatland than on slopes. A rain totaling 4.4 inches in 2-1/2 hours penetrated a bare granitic soil to a depth of only 7 cm. (11). About 80 percent of the rain was lost as runoff.

The splash-erosion process is affected by variation in either the size of raindrops, drop velocity, or rainfall intensity. Using rain applicators to apply spray to trays of soil, it was found that as the drop size increased from 1 to 5 cm. in diameter the infiltration rate decreased as much as 70 percent, and the erosion losses--measured in terms of the concentration of soil in the runoff water--increased up to 1,200 percent (10). As the size or velocity of raindrops increased, the concentration of soil in the runoff water increased and the infiltration rate decreased. This showed a direct relation between the energy expended by the falling raindrops and the resulting soil loss. It was also found that the concentration of soil in the runoff water varied with the time at which comparisons were made. This indicated that the erodibility of the soil surface changed during the run.

The amount of damage done by falling raindrops is proportional to their kinetic energy, which ranges from 1,000 to 100,000 times the work capacity of surface flow (5, 11). When raindrops strike bare soil, or thin films of water covering it, they blast it with a multitude of explosions. These blasts bounce water back

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Figure 6.--Splash erasion octs as o leveling agent. It moves slaping tapsoil in sheets. Much of the erosionol debris is deposited at the base af slapes. Thus the crests of hills are lowered while at the same time the valleys and depressions ore often filled.

Figure 7.--The impact of falling raindraps beating an the naked earth during vialent starms shatters the clads and soil crumbs and breaks down the sail structure into a puddled condition. The beoting, churning actian af these draps compact the soil's finely braken parts into an impervious surface mud.

into the air carrying with it, in muddy slush, fine particles of earth. These splashed particles reach varying heights, ranging up to more than 2 feet, and they move horizontally more than 5 feet on level surfaces. Their trajectories are shown in figure 1. This photograph shows a series of stages of the splash resulting from a drop of water falling from a height of about 7.5 feet onto a pan of soil, which cannot be seen in the picture. On bare soil which is highly detachable, more than 100 tons per acre may be splashed by the most beating types of rain.

On level surfaces, the splashed material tends to scatter uniformly over the surface in all directions when the raindrops have a vertical drop. In such cases, the outgoing splash normally balances the incoming splash in a given area. But when raindrops strike sloping land surfaces, the major portion of the splash moves downhill. Since most of this splash moves in a downhill direction, relatively large quantities of soil may be transported by raindrop splash acting alone. The percent of soil splashed downhill has been found to be 50 + the degree of slope of all the soil splashed (4).

The amount of raindrop energy dissipated on the soil during a storm may be measured indirectly by measuring the soil carried in raindrop splash (6). A favorable place to observe transportation by splash is on a large sandpile that is free of surface flow. The top of the pile will be lowered by splashing the sand particles downhill, while sand at the lower edge will be piled deeper and the pile made wider. The results of this same process are apparent on many small knolls and hummocks, and along the crests of many hills. Figure 5 is typical of these conditions, where the crests of hummocks, knolls, and steep hills in cultivated fields and on overgrazed pastures are often devoid of topsoil while a deep bank of topsoil may be found along the base of the slope. Examination of these soil banks often shows that they do not have the characteristics of alluvial deposits.

The splash process produces at least three different types of erosional damage: (a) Puddle erosion, (b) fertility erosion, and (c) sheet erosion.

Puddle Erosion

As previously stated, falling raindrops have great capacity to damage soils. The sharp impact, as the drops beat on the naked earth during violent storms, shatters the clods and soil crumbs and breaks down the soil structure into a puddled condition (14) (fig. 7). The beating and churning action of these drops compacts the soil's finely broken parts into an impervious layer of surface mud.

This compacted surface layer is made denser and more impervious as it collects colloids and other particles from the turbid rainwater that filters down from the surface. Eventually, the porosity of this surface layer is materially reduced by the infiltration of muddy surface materials. Then the important entrance channels to deep soils are closed. The soil-profile material can no longer absorb air freely, nor can it receive and store abundant supplies of rainfall.

A single storm leaves visible effects of this puddling only on the surface of the soil. These show as crusts on plowed fields (fig. 8). The surface is glazed like the icing on a cake. The puddling process may be demonstrated by playing a heavy spray from a garden hose on bare ground. Puddling can actually be seen taking place on the surface. Where the ground surface is protected by low-growing plants or by a cover of mulch, it is shielded against the impact of falling raindrops and puddling is prevented (1, 2, 11, 12). Under these conditions the soil retains its natural structure, and any water that accumulated on the surface remains clear.

Fertility Erosion

When raindrops loosen the soil and splash it into the air, nearly all of the particles that are dislodged seem to be 2 mm. or less in diameter. They also carry some particles larger than this. As these splashes fall back into the surface water, many of the finer particles are carried away (fig. 9) and the coarser material settles out after being moved a short distance downhill. This produces what is known as fertility erosion (13). It results in the accumulation of excessive coarse material on the surface (fig. 10) within a short time after the beginning of rainfall. Even during the first 2 minutes of rain, the splashed materials may be higher in sand and fine gravel than the original soil itself.

Storms of small drop size, which fall at relatively low velocities and of light intensity, intense rains of very short duration, or intense rains which terminate abruptly, tend to leave an excess of coarse particles on the surface of the field.

Even though the land is practically level, much of the organic matter and fertility-bearing elements of the soil may be floated away (fig. 11).

The action which produces fertility erosion can be demonstrated by washing a bucket of sandy soil in a washing machine. Just dump the soil in the tub while the agitator is working, and keep a small stream of water entering the tub in order to maintain a constant overflow. The overflow will carry out the fine and light

Figure 8.--The view in the middle foreground shows the puddling effect of a single rain on a cornfield. The surface is glazed like the icing on a cake.

materials as the agitator stirs them into suspension. Soon, nothing is left in the bottom of the tub but coarse sand.

Sheet Erosion

So-called sheet erosion is actually splash erosion. Because of the very nature of the splash-erosion process, it tends to remove the sloping topsoil in thin sheets. The effects are demonstrated in miniature every time beating raindrops flatten and level small sandpiles. It works about the same way on a hill, bringing material down from the crest and depositing it lower on the slope. The energy of the splashing raindrops is applied uniformly throughout the area on which the rain falls. This favors production of the greatest amount of soil movement at the crest of the hill, where the least amount of energy is required to transport soil and more of it can be devoted to dislodging the soil particles. At some point downhill, all of the energy of the raindrops may be consumed in resplashing soil that has been splashed down from above. Below this point, the land will not lose soil through the splash process acting alone. Figure 5 shows a typical pattern of erosion that is largely caused by raindrop splash where the greatest soil loss per unit area is near the crest of the hill and on the steepest and shortest slope.

While splash erosion alone can move quantities of soil downhill, it does not transport it away from the base of the slope to any appreciable extent. But there is a thin prechannel surface flow of water during the time that splash erosion is active. Some of the soil splashed is kept in suspension in the surface flow, which moves into rills and then to larger channels. The combined action of raindrop splash and the flow of water accounts for nearly all of the sediment removal from individual fields.

Surface-Flow Erosion Process

Flowing surface water is usually the major transporting agent when erosion is caused by rainstorms. This flow moves across the land in two principal forms. It may move as a shallow sheet of water across broad surfaces that have no perceptible channels, in which case it is referred to as sheet, or prechannel, flow. Or, it may move in rills, gullies, or valley channels, in which case it is referred to as rill or gully flow, or merely as channelized flow (fig. 12).

In contrast with the energy from falling raindrops, applied to the surface of the land vertically from above at velocities that may exceed 30 feet per second, surface flow of water

14-1481

Figure 9.--Organic matter, silt, and clay "picked" loose by falling raindrops and floated downhill by flowing surface water to be deposited in depressions or flooted off the field. The deposit on this cornfield is several inches thick.

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Figure 10.--Fertility erosion in a cultivated field -- organic matter, silt, and clay were splashed from the sand by splashing raindrops. The washed sand, appearing as light-colored deposits between the rows, was left in the furrows.

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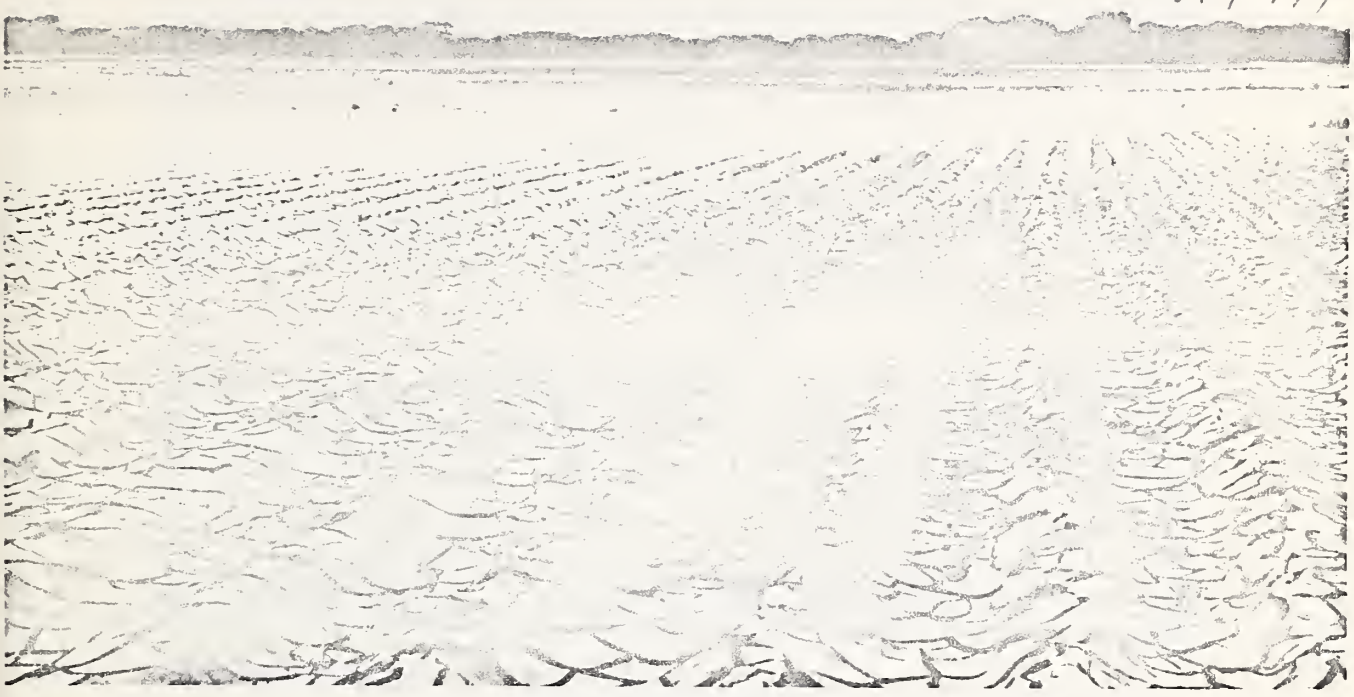

Figure 11.--Even though the land is level, much of the organic matter and fertility-bearing elements in the exploded particles of soil may still be floated off while much of the muddy water may settle into pockets or drain into openings in the soil. When the sun comes out, the surface mud bakes into an almost impervious crust, which when broken, is so fine that it is easily carried away by the wind.

ordinarily has velocities of not more than a few feet per second. On smooth surfaces, outside the rills and gullies, these velocities are usually less than one-fourth foot per second. Surface water tends to concentrate and take on the characteristics of stream or channel flow as it moves downhill (fig. 13). Whereas the results of raindrop erosion are most apparent at the top of hummocks and hills, erosion by surface flow is usually most apparent near the base of the slope, where the greatest amounts of surface flow concentrate (fig. 14).

The amount of force generated by surface flow of water is definitely related to the concentration and velocity with which it moves downhill. Running water gains the energy to perform work by gaining mass in its movement downhill, or by gaining velocity as it falls over a rapid change in slope (fig. 15). Maximum erosion occurs when the detaching and transporting capacities of surface flow are balanced. That is, when the surface flow contains just enough abrasive material to detach as much soil as the flow will carry. This condition of balance changes with each change in the erodibility characteristics of the soil. Beginning at the top of a hill, the transportation process usually tends to make the soil loss per unit area decrease with each increase in the length of slope over which the water flows.

Because the source of its energy is so related to the concentration and velocity with which it moves downhill, flowing water does not operate evenly over the surface of a field. Therefore, it could not cause so-called sheet erosion (4). Instead, it usually acts as a carving or grooving agent and roughens the surface by scouring (fig. 12).

Prechannel surface flow of water may be expected to be laminar in the absence of falling raindrops (2, 3, 4, 7, 9). Laminar sheet flow is without turbulence and its energy is all energy of translation (9). As the surface flow concentrates into stream or channel flow, it develops turbulence. The scouring and transporting capacities usually increase because the flow of turbulent fluids contains both energy of translation and rotational energy.

Turbulent flow cannot occur below the depth at which the velocities of laminar and turbulent flow are the same, for the reason that the stream lacks sufficient energy to sustain turbulent flow at shallower depths. When the velocities for laminar and turbulent flow are equal, the total translational and nontranslational energy per unit-volume of turbulent flow is nearly identical with the translational energy per unit-volume for laminar flow (9). At or near the point of equal velocities the flow may, therefore, be either laminar or turbulent.

Figure 12.--Once surface water becomes sufficiently concentrated it cuts rills and gullies and is known as channelized flow.

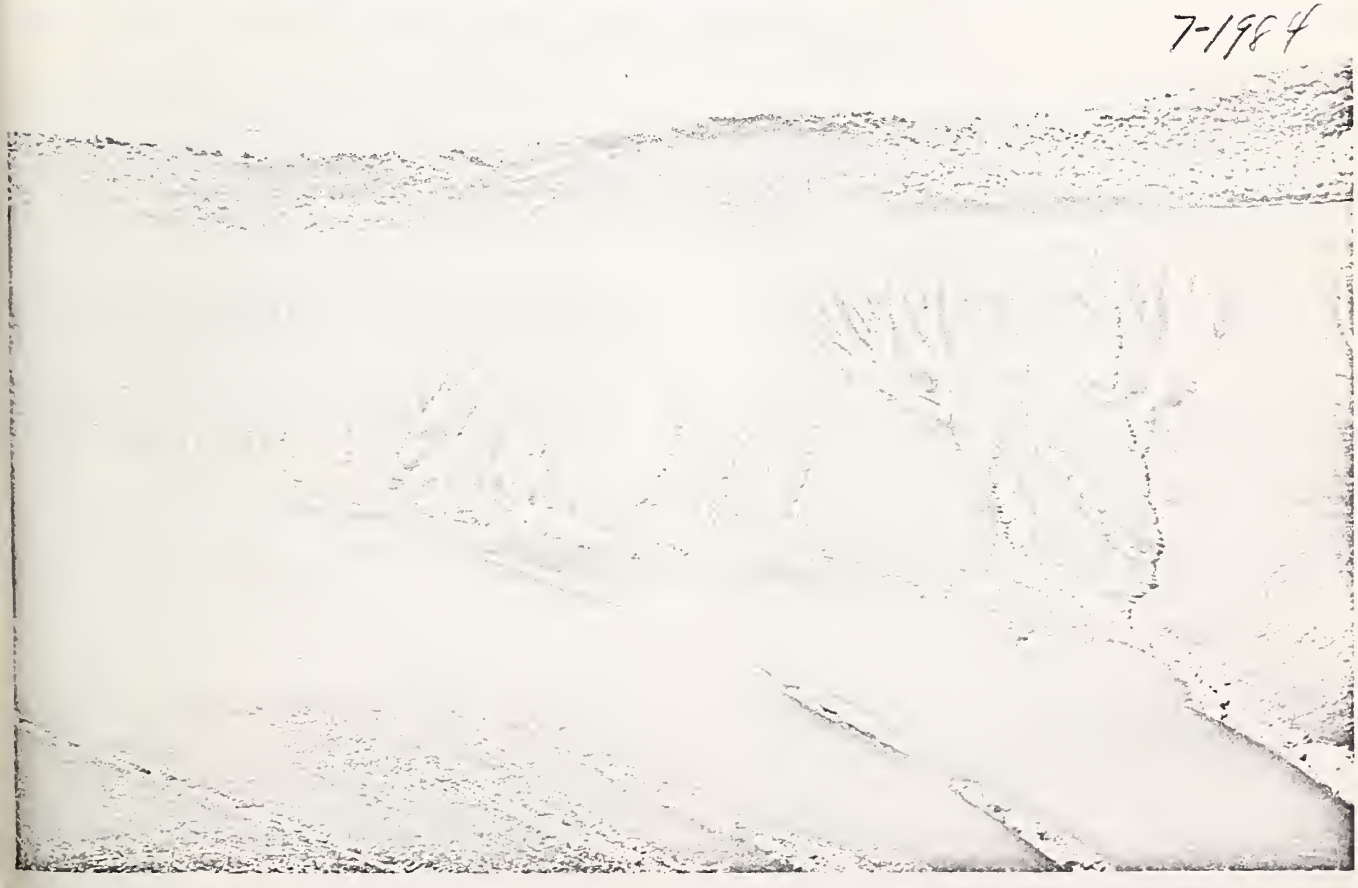

Figure 13.--Surface water tends to cancentrate and take on the characteristics of stream or channelized flow as it maves downhill.

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Figure 14.--Surface flow does its greatest damage when water accumulates to form channels. The major part of erosion occurring outside of rills and gullies is caused by raindrop splash.

Or it may change from one to the other without any change in energy. Laminar flow, however, cannot become turbulent flow at lower velocities. Laminar flow may persist at higher velocities, but the energy-content of the water is greater than that required to sustain turbulent flow. A change from laminar to turbulent flow can take place apparently at any velocity exceeding the point of equal velocities. If, however, it takes place at a higher velocity it will be accompanied by a surge or change of water level in the channel. The point of equal velocities apparently fixes the lower limit of turbulent flow in a channel.

The velocity of laminar sheet flow varies as the square of the depth. The velocity of turbulent flow in a wide channel varies as the two-thirds power of the depth (9). For a given channel roughness, temperature, and slope there is always some depth at which the velocity of laminar and turbulent flow would be equal. The velocity of laminar flow of shallow depths is less than would be the velocity for turbulent flow.

The erosive power of clear water is assumed to vary as the sixth power of the velocity. It is believed, however, that the different characteristics of muddy water often cause this erosive factor to vary through much wider limits than do changes in velocity.

The energy of surface flow is a function of mass and velocity of the flowing water. The mass is determined by the quantity and quality of the flow. The velocity for any given mass is affected principally by the length of the path of flow for each unit of vertical fall, and the resistance to flow in each unit of slope length. A reduction in either the mass or the velocity will reduce kinetic energy (7).

The detaching and transporting capacity of surface flow may vary, each independently of the other. If, for example, clear water is permitted to flow over well compacted clay soil, it may not have sufficient detaching capacity to cause much erosion and the runoff will be clear. But if soil containing highly abrasive fractions is injected into this flow at the point where the clear water flows over the clay soil, the detaching capacity of the water will be increased and the rate of erosion will be accelerated. Increasing the amount of soil injected into the flow will increase its detaching capacity. At the same time, it will decrease the transporting capacity. Increase the amount of soil in the flowing water to the point where it is all that the flow can transport, and there will be very little erosion of the clay soil.

An increase in the energy of surface flow will increase its carrying capacity, and generally will cause an increase in rates of erosion. Increases in soil erosion which result from increases in velocity may vary greatly in different soils, and even within the same soil. No fixed relationship exists between the velocity

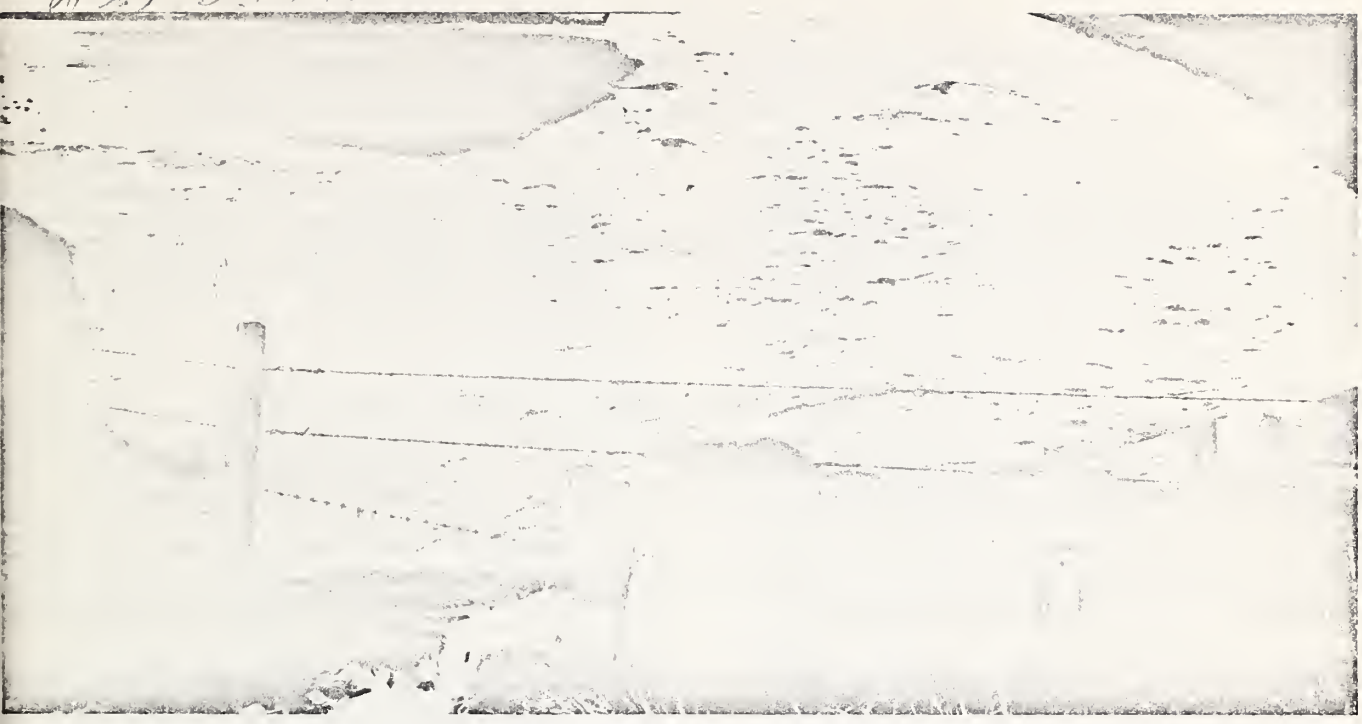

Figure 15.--Flowing surface water gains energy to perform work by gaining mass as it concentrates at the foot of the slope, or by gaining velocity as it falls over a rapid change in slope.

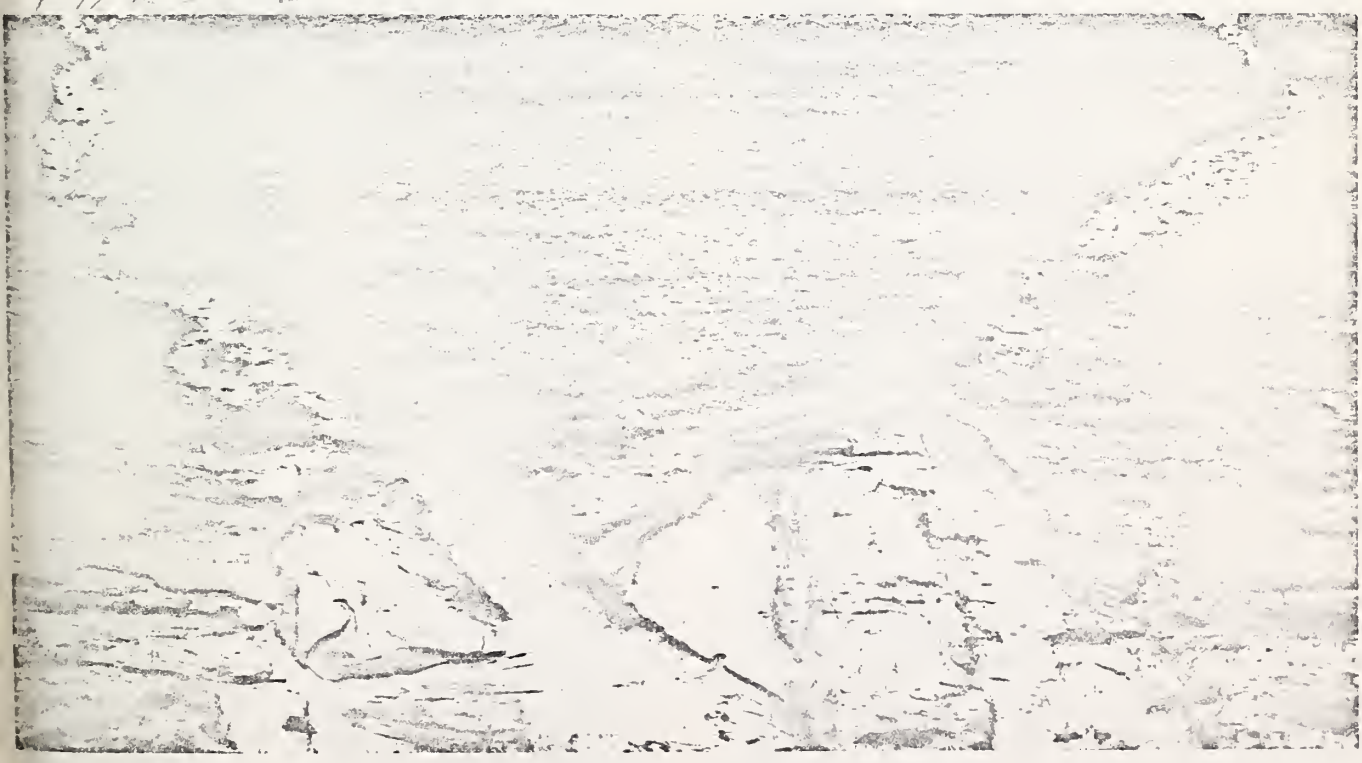

Figure 16.--Soil transportation in these gullies is by channelized flow. Between the gullies the soil is transported in prechannel stages and splashing raindrops impart to this shallow water a high soil-suspending capacity.

head and rates of erosion during the course of a single rainfall, because conditions within the soil which affect its erodibility may undergo change while the soil is being wetted. During storms, these changes occur within a matter of minutes. They usually come about more slowly during the drying period between storms. Just as an emery wheel traveling at a fixed speed will abrade different metals at different rates, so will a given amount of flow energy erode soils of different erodibility at different rates. However, high energy of surface flow may cause more or less damage to all soils, regardless of type or of its condition. It may be assumed that any increase in velocity head increases soil erosion.

When broad sheets of water move across open fields in prechannel stages during rainstorms, velocities which have sufficient soil-suspending capacity will seldom develop. It is the energy of turbulence imparted to flow by splashing raindrops that gives it much of its suspending capacity (1, 2, 3, 4, 6, 7, 9)(fig. 16). The same is true of many shallow channelized flows. Raindrops bombarding these water surfaces may often increase their transporting capacity by several hundred percent.

The kinetic energy imparted to shallow surface water by impact of raindrops not only increases the transporting capacity of flowing water, but it may give to standing water a soil-suspending capacity. Standing water that is churned by splashing raindrops has been found to contain as much as 20 percent of soil. This soil content is affected but little, if any, by velocity when the standing water starts to flow so long as it moves across smooth surfaces as sheet flow.

The soil-transporting capacity imparted to shallow surface water by falling raindrops varies widely with sizes of drops and velocities of their impacts. The turbulence imparted by splashing raindrops may cause much coarse sand and some gravel to be moved by surface water that is barely flowing. Under certain conditions, raindrop impact can at times move stones as large as 10 mm. in diameter when they are partially or wholly submerged in water (8). Raindrops striking these submerged stones cause them to rise and frequently move some distance downhill. Surface flow assists the downhill motion even though, if acting alone, it would not move them. With the removal of the raindrop impact from the flowing water, both the detaching and transporting capacities rapidly decrease. This explains why muddy water passing under an automobile parked on a street drops most of its load. The car intercepts the raindrops and the flowing water quickly loses its transporting capacities.

If the surface of a field is fully protected against the impact of raindrops, very little soil will be transported except that which is detached and moved by channelized flow (fig. 17). In such cases, the topsoil between rills and gullies may remain practically unimpaired throughout the storm.

Free water acquires both rotational and translational energy as it concentrates to form channelized flow. The rotational energy detaches soil by scouring. The energy of translation enables the flowing water to transport the detached material downhill. Since these energies are concentrated and applied to restricted areas of the ground surface, the flowing water carves grooves into the surface soil (fig. 13). In their initial stages, and near the crest of slopes, these grooves are known as rills. Rills are preceded by small undulations formed on the surface of the ground by the impact of raindrops during hard rains (11). As the water continues to concentrate and acquires additional energy for scouring, these grooves become deeper and broader and eventually some of them develop into gullies. Scour erosion made the Grand Canyon and carved out our river systems.

The energy of surface flow tends to concentrate and be greatest on the longest slopes. Each additional unit of slope length at the lower end of a watercourse tends to increase the quantity of water that flows off the lower end of the slope. It also adds a unit of head through which the water must be lowered in the runoff process. As a result, surface flow tends to produce the largest gullies and cause the greatest soil losses near the lower ends of the longest slopes. Figure 13 shows a typical pattern of soil erosion that is caused mainly by flowing surface water Note how the sizes of the gullies increased from top to bottom of the hill.

Usually, shallow surface flow acting alone cannot detach soil in thin sheets or layers from broad surfaces of a field. Irregularities in surface smoothness and in the soil's structural properties cause the flowing water to form minor rills just as soon as the scour process becomes active. Once these minor rills are formed, the only significant erosion caused by the surface water will be within these channels (fig. 18).

If the soil is both highly detachable and highly transportable, so that only small amounts of flow can detach and transport it, small rills may be formed very close together. Figure 18 shows a field of such soil in the Palouse country in Washington. Small rills occur every few feet on that field. These channels drain their water and soil loads into several larger rills, which extend down the full length of the hillside. This field's soil is highly detachable, and it is higher than average in transportability. It is considered to be a highly erodible soil.

Gullies crossing such fields are fairly uniform in cross section. This indicates that the

Figure 17.--Falling raindrops and flowing surface water were both active in detaching and transporting soil on the unprotected cultivated area across the center of the photograph. Flowing surface water in the form of channelized flow was the chief detaching and transporting agent in the pasture area in the foreground.

gully flow took on no increased amounts of soil as it moved downhill. Since the soil is highly detachable, it would be reasonable to expect the flow to take up more soil and make the gullies larger near the base of the hill if there had been capacity to transport more soil. Apparently, however, the surface water was almost fully charged from the time the raindrop impact produced a muddy slush on the surface until the time of runoff at the base of the slope. The shallow flow moving into these gullies is capable of transporting as high percentages of soil as is the gully flow itself. Actually, the splashing raindrops may keep the thin layer of surface water even more highly charged than the gully flow, if the soil is bare and highly detachable.

This condition, in which the water flowing into the gully contains as much soil as the gully flow can transport, usually will continue for only a short period at the beginning of a storm. As the storm progresses, the surface soil tends to become compacted and its detachability decreases. Then the water flowing into the gully may be low in soil content, and the gully flow may continue to take up soil en route until it reaches the very bottom of the slope. Thus, it may be assumed that gullies of the type described above may have been caused by a storm of short duration or by failure of the soil to consolidate and undergo a decrease in its detachability.

A soil that is of low detachability will withstand considerable concentrations of surface flow before large amounts of its materials become dislodged. A soil that is of low transportability will withstand considerable concentrations of flow before the detached particles are transported. Because of this, the rills will tend to be considerable distances apart in soils that are of either low detachability or low transportability. Figures 19 and 20 show the typical erosion pattern developing on these erosion-resistant soils. Only one rill of appreciable size was formed during a heavy rainstorm on the field shown in figure 19. Differences in soils at various elevations on a hillside, changes in slope between the top to bottom of a hill, and a lack of uniformity in other factors may prevent development of gullies of the type described above. If soils are of either low detachability or of low transportability, or both, however, these factors will tend to make any gullies that are formed have cross sections which increase in size from top to bottom of a hillside.

There are at least three different soil-detaching processes in scour erosion. They may be termed rolling, lifting, and abrading.

When surface flow moves across a smooth soil surface, it tends to roll or drag soil particles along with it. Surface velocities may even reach such magnitude that they will dislodge particles from their moorings in the soil mass.

Figure 18.--It will usually be found impossible to make shallow surface flow, acting alone, detach soil in thin sheets or thin layers from broad surfaces of a field. The effects of irregularities in surface smoothness, together with the effects of other irregularities in the soil's structural properties, cause the flowing water to form minor rills just as the scour process becomes active.

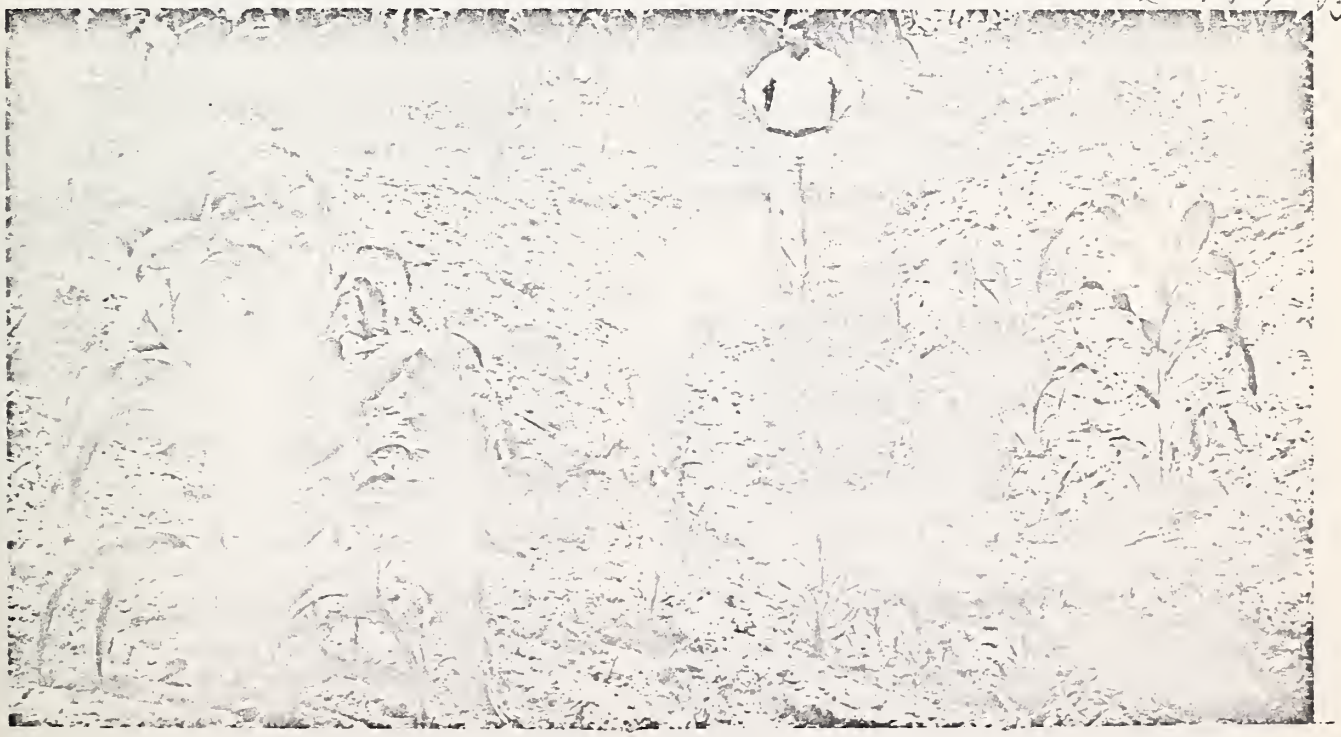

Figure 19.--This soil is less detachable, and the single gully shown does not reach to the upper edge of the watershed. When the water moves downhill, its detaching capacity increases, and when soil detachment limits the erosion process this increased detaching capacity will accelerate the erosion.

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Figure 20.--On this soil the gullies increase in size as they approach the bottom of the slope. This could be caused by the flow not being fully charged, in which case its detaching capacity may continue to increase as the gully flow moves downhill.

This process of soil detachment is known as rolling. The extent of soil particle dislodgements by this process will depend primarily on (a) how well the particles are moored and (b) the energy of the surface flow.

The soil detachment process described as lifting occurs when water moves upward past soil particles on the surface. A surface that contains many small depressions between clods and crumbs of soil will retain considerable amounts of free water which have no horizontal velocity, while the water just above it will be flowing. This difference in velocities sets up pressure differences between the layers, which undergo change with each pulsation in the upper layer. The changing pressure differences cause vertical currents and eddies to be set up, and the upward flowing water may lift soil particles from their moorings and set them in motion. Here again the amounts of soil materials detached by this process depend upon (a) the detachability of the soil, and (b) the energy of flow.

The soil detachment process known as abrading occurs when soil fractions in motion in the flow are pounded against, or dragged along in contact with, the surface soils. The amounts that will be abraded will depend upon the factors of (a) energy of the surface flow, (b) soil detachability, (c) amounts of abrasive materials in transport, and (d) abrasive properties of the materials in transport.

Soil Deposition

Soil materials deposited by moving water are usually separated by particle sizes. The first materials to be deposited will be those of lowest transportability, whereas the materials of highest transportability will be deposited last--the farthest downstream.

The amounts of fine and highly transportable materials that are removed from a watershed tend to be proportional to the amount of splash erosion. Soil aggregates eroded by the splash process are broken up more finely than when the soil is eroded by the action of flowing water. This results in a greater release of silt and clay fractions and organic matter, which are highly transportable. These fine and light materials are often floated miles downstream to be deposited in large reservoirs. The less easily transportable parts of the eroded soil are usually deposited upstream. Thus, farm ponds and small upstream reservoirs located

near the bases of sloping fields are likely to be filled with the products of rill and gully erosion, which are composed of coarser materials. On the other hand, large downstream reservoirs are most likely to be filled with products of the splash-erosion process--the light organic matter and silt and clay fractions which are much more highly transportable.

One may gain a general idea of the effects of splash erosion on streams and reservoirs by comparing streams in the wooded and grassed mountainous areas with streams of much lesser gradients in more nearly level cropped areas. The water in the mountain streams is often crystal clear but the water in streams draining cultivated areas is heavily charged with erosional debris. This condition exists despite the fact that the flow usually moves to mountain streams over much greater energy gradients than the gradients of cropped fields. The surface of the mountainous areas usually has enough tree and grass cover to check splash erosion effectively.

Other things being equal, the steeper the slope gradient the faster will be the rate at which erosional debris is moved downhill from the crests of hills by raindrop splash. It moves faster at higher levels than it does further downhill where gentler slopes are usually encountered. The organic matter and the light silt and clay particles, which are the fertility-bearing elements of the topsoil, are moved out first. They usually are not deposited until the flowing water comes to rest in depressions at the bases of slopes or in ponds or reservoirs. The coarser materials in the topsoil follow, and eventually the materials comprising the subsoil, are moved by erosion. This erosional debris may be found deposited on many soils all along the slope course, from the point of origin to the sea.

Deposition is particularly noticeable where breaks in the slope slow the flow of water abruptly, or on the lower portion of slopes where raindrops expend most of their energy in resplashing soil material that has been splashed down from uphill. The movement of topsoil that is splashed from the crest of a slope becomes slower on the gentler slopes near the bottom of the hill. This causes "telescoping" of the soil. That is, soil from high on the slope overtakes the material that is in motion lower down. The result is that topsoil piles up in a bank near the bottom of the hill. Often this is later covered with subsoil brought down from uphill.

This process may be illustrated by what happens when a sandpile is leveled by rainstorms. The material at the base of a sandpile tends to be more transportable than the material near the top. This is because of the process of selective erosion, which causes fine sands to be moved downhill more rapidly than the coarser materials. The phenomenon will be most apparent in early stages of erosion. After many years of unchecked erosion, the coarse sands may be carried downhill also. On the very crest of those hills, where the slopes are less steep, however, very little of the fine sands may be washed out.

The situation is usually different on clay soils. Soil materials at the base of a clay slope are usually less transportable than those higher on the hillside, largely because of selective transportation. When deposits occur near the base of the hill, they include a high percentage of the materials that are of low transportability. The clay fractions and other very light materials may float far beyond the base of the slope.

Evidences of erosion by channelized flow of water are most readily apparent. It is easy to watch a few large streams as they carry soil down the hillsides, often transporting tons of erosional debris as fast as a fleet of large trucks might move dirt away from a power shovel. But it is impossible for us to see the billions of raindrops doing the "pick and shovel work" which loads these water streams with the fertile topsoil from the many acres of smooth field surfaces.

Most of the soil laden streams, and the gullies they carve in the hillsides, are outward manifestations of deeper and more basic troubles. As the raindrops "pick" the soil loose, they also separate the particles, break down the granules. They also mix, puddle, and compact a shallow layer of the surface soil until a highly impervious surface seal is formed. In some soils, this seal will almost "waterproof" the land. It increases and determines to a large extent the nature and character of the deposition that results.

Summary

Falling raindrops and flowing surface water are the two chief erosive agents in the water-erosion process. Each is a complete erosive agent within itself, capable both of detaching and transporting soil. They are the most destructive, however, when they team up with the falling raindrops splashing soil loose and feeding it into the flowing surface water to be swept downhill.

In the process of water erosion, raindrops serve chiefly to detach soil particles. Transportation of the soil particles is chiefly by surface flow of water. Although the primary role of the falling raindrops in the erosion process is detaching soil particles, they play a secondary role which often is equally as important. During periods of heavy impact storms on unprotected land, they splash large quantities downhill, and also impart transporting capacity to surface water by keeping it turbid.

The energy of falling raindrops is applied vertically downward while that of surface flow is usually applied parallel to the surface. Falling raindrops and surface flow produce widely different effects on the soil. Raindrop splash, or the splash-erosion process, removes the sloping topsoil in thin sheets. It acts as a smoothing and leveling agent. It produces at least three important types of damage, that is, puddle erosion, fertility erosion, and sheet erosion. Flowing surface water erodes by scouring or grooving the soil. It is a roughening agent and is responsible for rill and gully formation.

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